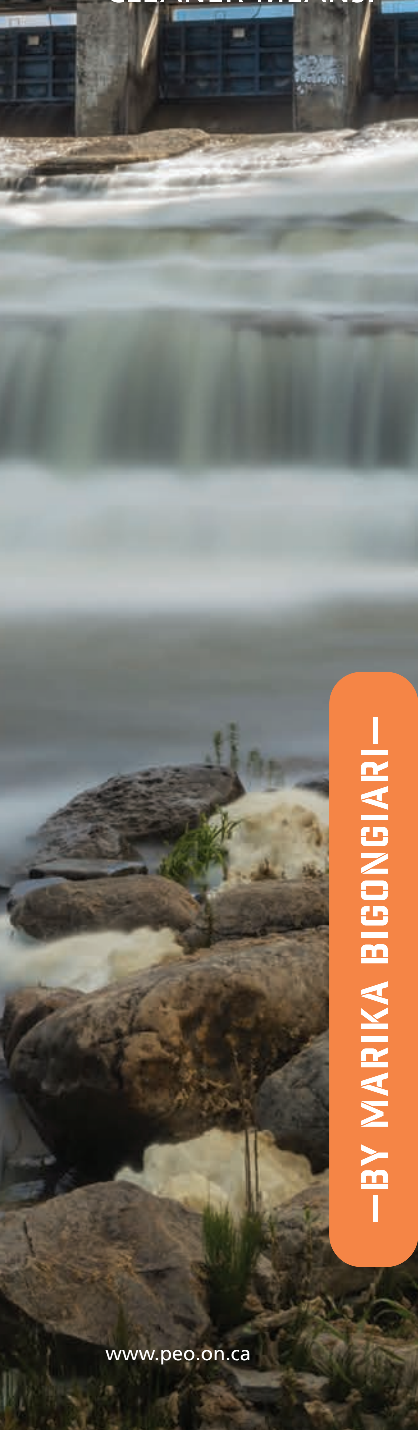
The Healey Falls Dam on the Trent-Severn Waterway near the town of Campbellford, Ontario, controls the flow of water to facilitate the production of hydroelectric power. It is estimated the facility generates approximately 100,000 megawatt-hours of renewable energy per year.

ENGINEERS WEIGH IN ON THE SHIFT TO RENEWABLE ENERGY

THE ENERGY SECTOR IS BUZZING WITH ENGINEERS RACING TO DESIGN AND SUPPORT SUSTAINABLE ENERGY OPTIONS AND INFRASTRUCTURE. WE CONSULT WITH THREE ENGINEERING PROFESSIONALS WHO EMPHASIZE THE IMPORTANCE OF DELIVERING ONTARIO'S ENERGY NEEDS THROUGH CLEANER MEANS.

—BY MARIKA BIGONGIARI—



Renewable energy—also known as "green" or "clean" energy—comes from sources that are inexhaustible, such as the sun, wind, rain, water currents or tides and geothermal energy; and given the environmental impact of using fossil fuels, the clean energy sector creates a lot of buzz because of the role it plays in the fight against climate change. In addition to creating more efficient solutions to conserve our natural resources, clean energy also aims to create cost savings for consumers. According to Clean Energy Canada, Canada's clean energy sector is growing faster than the rest of the country's economy and is attracting tens of billions of dollars in investment every year, creating jobs in every province and across industries—and Ontario has the biggest piece of the pie, making up 39 per cent of Canada's clean energy GDP in 2017. Engineers are responsible for many aspects of innovation in this space, including ensuring the requisite infrastructure is in place to meet the province's energy needs.

TRANSITION TECHNOLOGIES

Sometimes progress is about the intermediary steps. Although more sustainable forms of power generation have a clearly positive impact on the environment by reducing our reliance on non-renewable resources, such as coal, oil and natural gas, those non-renewable resources still make up a significant portion of Canada's energy picture. For that reason, energy waste mitigation initiatives such as carbon capture and storage (CCS) minimize the damage created by using those resources. This is important, especially during the transition to more sustainable methods, explains Marina Freire-Gormaly, PhD, EIT, an assistant professor and researcher in the Lassonde School of Engineering's department of mechanical engineering at York University. Freire-Gormaly, who holds a master's degree in the area of carbon management and sequestering carbon dioxide in deep geological formations, is interested in an integrated systems approach to energy sustainability, such as understanding how we can better combine existing and new technologies to more effectively utilize the power, with her most recent work focused on solar photovoltaic powered reverse osmosis water treatment systems for remote and off-grid communities. She has also worked on the pore structure characterization of rocks to study CCS technology, in which carbon dioxide (CO_2) is injected into deep saline aquifers for permanent storage. It's an important intermediary technology that's sometimes overlooked in favour of greener options, but it's one that several Ontario energy firms are pushing forward.

CCS involves capturing CO_2—either at the source, thereby preventing it from reaching the atmosphere, or by extracting it from the air after it's been emitted—and then storing it in a secure place, generally deep underground or underwater. Instead of allowing the CO_2 emissions to leave the plant through the stack to the atmosphere, for example, the CO_2 is first captured, then transported and finally stored underground or in balloons submerged in bodies of water. The underground reservoirs where the CO_2 is injected might be unmineable coal seams, depleted oil and natural gas reservoirs or deep saline aquifers, Freire-Gormaly explains.

The practice is not without controversy, with opponents pointing out the environmental risks inherent to transport and storage, stressing the need to abandon fossil fuels altogether in favour of clean energy solutions. However, since fossil fuels remain a significant source of energy in Canada, waste-mitigating technologies such as CCS play an important role in the transition to a clean energy future. CCS takes what is otherwise a waste-producing form of energy and helps shift it towards carbon neutrality. "Carbon capture and storage is considered a sustainable energy technology or a transition technology as we move from a carbon-intensive economy to renewable power," Freire-Gormaly observes. "It's a way to reduce the emissions from conventional fossil-fuel-based energy generation—for example, coal, oil or natural gas power plants."

According to the Canadian government, CO_2 accounts for 80 per cent of greenhouse gas (GHG) emissions produced by Canada, and the majority of those emissions are energy related—so mitigating CO_2 emissions due to concerns related to the environment and climate change is becoming an increasing priority. In 2015, the United Nations (UN) General Assembly adopted their 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs)—among them, a stand-alone goal on energy, SDG7, which seeks to ensure access to affordable, reliable and sustainable energy for all. The UN asserts that improved energy efficiency could account for 40 per cent of the emissions reductions needed to achieve their sustainability agenda and the Paris Agreement on climate change.

One of Freire-Gormaly's recent projects was helping to develop a related report on Canada for the World Bank Readiness for Investment in Sustainable Energy (RISE) project. RISE provides a quick overview of a country's policies and regulations in the energy sector by assigning a score under three pillars—energy access, energy efficiency and renewable energy—using the standards outlined by the Sustainable Energy for All initiative. Sustainable Energy for All is an international organization with close ties to the UN that works with governments, the private sector and other key groups to drive decisive and swift action towards achieving UN SDG7. RISE assigned Canada an overall score of 90, based on sub-scores of 82 for renewable energy, 86 for energy efficiency and 100 for electricity access.

In the face of climate change, population increases and our need for more energy, Freire-Gormaly maintains that sustainability is critical when considering our energy needs in the long term. "There will be more severe storms, temperatures and eventually climate refugees with mass migrations of people," she warns. With higher temperatures, we will need more energy to cool our homes and workplaces, and in the case of severe storms, we will need a more resilient electricity grid—and distributed sources of power generation and mitigation technologies can support this. "With mass migrations, we need to be prepared, as a sparsely populated country, to welcome new waves of immigrants and have the capacity in our electricity system to accommodate our energy needs and an industrial sector," Freire-Gormaly notes.

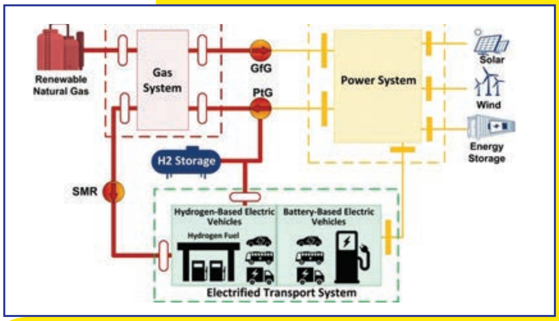
INTEGRATED ENERGY SYSTEMS

Hany Farag, PhD, P.Eng., an associate professor in the department of electrical engineering and computer science at Lassonde School of Engineering and principal investigator of the Smart Grid Research Laboratory at York University's Bergeron Centre of Engineering Excellence, is working in the trenches in the fight to move Canada toward a greener energy future. He's been developing timely and groundbreaking solutions to address key problems and integration barriers facing energy sector stakeholders, public transit operators and governments. His recent research focuses on the integration of power and natural gas systems, electrification of transportation (e-transport) systems, energy storage systems and smart grids. "Canada's climate change actions have mandated the urgent need to cut down GHG emissions from the most polluting sectors: energy (26 per cent) and transportation (24 per cent). Increasing the hosting capacity of distributed and renewable energy resources, electrification of transportation and the production of renewable fuel and natural gas have been identified as the key low-carbon solutions to help meet GHG reduction targets," Farag explains.

The deployment of low-carbon and green technologies is creating a paradigm shift in the way energy is generated, traded, distributed and utilized. As such, it also disrupts the logistics and operation mechanism of, for example, public bus transit systems and is accompanied by serious technological and economic challenges. "Among these challenges, maintaining the sustainability of low carbon-based energy and transport systems is the most salient," says Farag, who suggests that power, gas and transport systems could potentially be integrated into a unified framework using renewable energy, electric vehicles and hydrogen generation and storage facilities. "For instance, the surplus of renewable energy resources can be stored in battery energy storage systems or converted using utility-scale electrolysis to hydrogen," he explains. "Also, hydrogen can be produced from both natural gas and renewable energy and could potentially be utilized to power fuel cell vehicles. Transportation systems could become fully electrified using plug-in electric vehicles or, with the advancement of hydrogen technologies, a mix of fuel cell and plug-in electric vehicles might appear."

Farag's current research objectives include the development of an optimization toolkit to design integrated energy systems (IESs), including concurrent design and operation scheduling of IES technologies to minimize GHGs generated by the three integrated systems. Farag says that the toolkit will be used as a decision-making support system to evaluate and enhance the technical and economic aspects associated with the wide adoption of hydrogen infrastructure and quantitatively compare them to their clean counterpart (for example, battery-based storage and plug-in EV technologies). Farag is also working on the development of a distributed communication platform and transactive energy management system, explaining that the decentralized nature of a typical IES structure needs

GfG: gas fired generator
PtG: power to gas
SMR: steam methane reforming



A conceptual diagram of a proposed integrated low carbon/green energy transport system, which the research of Hany Farag, PhD, P.Eng., aims to investigate and advance. The figure shows that power, gas and transport systems could potentially be integrated into a unified framework using renewable energy, electric vehicles and hydrogen generation and storage facilities.

superior distributed communication and control systems. "As such, this objective aims to develop a fully distributed communication platform (DCP) that could enhance message reliability, interoperability and scalability among distributed control units by utilizing Internet of Things technologies," Farag says. "The DCP will be used to develop a blockchain-based transactive energy system and pricing mechanisms to control and manage IES entities and enhance their resilience by enabling a distributed ledger to maintain ordered time-stamped data blocks that cannot be modified retroactively." Another objective is shoring up the cyber-physical security of IESs. Farag points out that as the stage is being set for the coordinated operation of integrated low-carbon power, natural gas and e-transport networks, critical operating data and control signals need to be communicated within the integrated systems, in which case, new measures for the cybersecurity of IESs must be developed. Farag aims to identify the issues that might challenge the cyber-physical security of IESs and develop new initiatives to address them. "In this regard, innovative distributed-based solutions will be developed in order to strengthen the capability of IESs to prevent, prepare and respond to and recover from cyber threats," Farag says.

HYDROPOWER'S GREEN ROOTS

Amidst all the talk about new technologies, hydropower is sometimes forgotten, despite being one of the most well-established and broadly used forms of power today. Hydropower, or hydroelectric energy, harnesses the power of water in motion, such as that flowing through a river, dam or waterfall, to generate electricity by converting the potential energy stored in the water to mechanical or kinetic energy. And even if it doesn't always come to mind when one thinks of renewable energy, clean energy is exactly what it is, explains Maria El-Zeghayar, PhD, P.Eng., a generation engineer at Portage Power. The fuel that powers hydro, which is the flow of water in the river, is free, and it's flexible, especially when the upstream reservoir has usable storage. "Hydropower can provide a base load and many grid services like operating and spinning reserves or frequency regulation," El-Zeghayar says. "It plays a key role in maintaining stable and reliable transmission and distribution networks."

Canada has a significant installed hydropower capacity, mainly in Quebec, British Columbia, Manitoba, Ontario and Newfoundland and Labrador, she explains. In Ontario, hydropower is the biggest producer of electricity. (Nuclear power is a close second.) According to Ontario Power Generation, hydroelectricity has a generating capacity of 7475 megawatts produced by 66 generating stations and 241 dams. "Most of these generating stations have been operating for many decades," El-Zeghayar notes. "More recently, utility scale wind and solar power have been developed across Canada, and

"AS ENGINEERS, WE CAN CONTRIBUTE TO THE TECHNOLOGICAL DEVELOPMENT, SAFE INSTALLATION AND OPERATION AND THE POLICIES TO ENSURE EVERYONE HAS ACCESS TO SAFE, CLEAN AND RELIABLE ELECTRICITY." –Marina Freire-Gormaly, PhD, EIT

we're starting to see development of distributed generation and distributed storage. All of these will play a critical role in a sustainable low-carbon future."

In the hydropower trenches, El-Zeghayar manages the technical aspects of running and maintaining hydropower generating stations and dams, including their design, construction, capital planning, dam safety, permitting and maintenance strategy, and a big part of her work involves respecting and protecting the environment. "We're committed to building a sustainable energy future that benefits people and the planet through our clean generation practices and community-minded approach," she says. When building the new Chaudière Falls Expansion, Portage had three goals to meet: produce clean, renewable energy in an environmentally responsible way; be an open public space to be enjoyed by all; and serve as a place of recognition and celebration of Canada's First Nations and Ottawa's industrialist past. In addition, the project was designed to have minimal-to-zero impacts on the visual, natural and aquatic environments. "To ensure safe fish passage through our facility, for example, we've incorporated leading technological solutions to protect migrating American eel, which are endangered under the *Ontario Endangered Species Act* (ESA), and facilitate their upstream migration past the numerous hydro-electric facilities at Chaudière," El-Zeghayar says. "In addition, there are new spawning beds built downstream to promote the recovery efforts associated with sturgeon—also endangered under the ESA."

The proliferation of distributed energy resources (DERs), or the diversification of where energy is sourced, represents a significant shift in how electricity systems operate. DERs might include a combination of solar panels, electricity storage, natural gas generators or hydrogen fuel cells, for example. Demand-side management, also known as energy management or demand-side response, is the optimization and modification of energy consumption through various methods, including consumer education and financial incentives. Because DERs are generally smaller operations serving smaller geographical areas, El-Zeghayar sees distributed energy resources and demand-side management growing considerably in the near term, which, she says, will bring generation and storage closer to the load, or consumers, eliminating the losses incurred through long-distance travel through transmission lines.

From designing the technology and constructing generating facilities and transmission networks, operating and maintaining assets and running large-scale systems like the Ontario grid, El-Zeghayar says there are places for engineers everywhere: "There are endless opportunities for engineers across the entire technology and asset life cycles related to green energy." El-Zeghayar reflects on how the work engineers undertake in the energy sector is especially critical in today's climate: "Sustainability is essential to build a future that is resilient to climate change," she says. "It is fundamental to the low-carbon future required for the good of the planet and all future generations of life that inhabit it. The costs of wind and solar power are now competitive with the former polluting cheap sources of thermal electricity. The excuses are gone and the time for positive change is now." **e**